a) Make a list of common acids and bases found in your school or home. When possible, include both the name and formula for each substance you test.

6. Dispose of all chemicals as directed by your teacher. Clean and put away any equipment as instructed. Clean up your workstation. Wash your hands.

7. Here are two activities that display the characteristics of acids and bases in a colorful way. Your teacher will show you these as demonstrations.

- Paint a message on a large sheet of paper or poster board using phenolphthalein indicator solution. (How about painting a message announcing your **Cool Chemistry Show**?) Allow the message to dry completely and hang the paper/poster board where everyone can see it. Use a window glass cleaner that contains ammonia water and when you are ready to reveal the message, lightly spray the design with the basic solution. (The secret message can also be revealed with a dilute ammonia solution. As the ammonia evaporates, the secret message that has been revealed will disappear again.)
- Rinse a small beaker with a strong acid and label it "A." Rinse another small beaker with a strong base and label it "B." Let both beakers air dry. In another beaker (label it "I") add 20 drops of phenolphthalein indicator solution to about 50 mL of distilled water. When you are ready, pour some of the solution from beaker "I" into beaker "A." Then pour the solution from beaker "A" into beaker "B."

a) Record your observations.

b) Account for the observations in each case.

Caution must be used with these sprays, because they can cause eye damage if they get into the eyes.

Chem Talk

ACIDS AND BASES

Arrhenius' Definition of Acids and Bases

Acids and **bases** were first classified according to their characteristic properties. As you've experienced, acids and bases have different, distinct interactions with indicators (substances that change color with changes in the acidic or basic nature of another material). Some acids react with metals, while bases do not. Bases have a characteristic bitter taste and slippery feel, while acids have a characteristic sour taste. In fact, the term, acid, comes from the Latin word, *acidus*, which means sour. Acids and bases are also good conductors of electricity.

Chem Words

acid: a substance that produces hydrogen ions in water, or is a proton donor.

base: a substance that releases hydroxide ions (OH^-) in water, or is a proton acceptor.

In the 19th century a chemist named Svante Arrhenius attributed the characteristic properties of acids to their ability to produce hydrogen ions when dissolved in water. If you look at the formulas for many common acids (HCl, H_2CO_3, H_2SO_4), you'll notice that they all have H as a common element. When these acids are added to water, a hydrogen atom can be drawn off into the water solution. The hydrogen atom leaves an electron behind, forming a positive hydrogen ion (H+) and a negative ion. Consider the action of hydrochloric acid in solution:

$$HCl_{(g)} \xrightarrow{water} H^+_{(aq)} + Cl^-_{(aq)}$$

The chemical equation shown above is valuable because of its simplicity. However, in reality, the hydrogen ion (H^+) is simply a proton and readily attaches itself to a water molecule. The result is called a hydronium ion (H_3O^+).

H^+	+	H_2O	$\rightarrow$	$H_3O^+_{(aq)}$
hydrogen ion		water		hydronium ion

To be more complete, the chemical equation above could be written as shown below. (Your teacher may allow you to use the simpler form of the equation—using the hydrogen ion as opposed to the hydronium ion).

$$HCl_{(g)} + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

Arrhenius also addressed bases and their characteristic properties. He defined a base as a substance that produces hydroxide ions (OH^-) when dissolved in water.

Let's look at a base using Arrhenius' definition. When solid sodium hydroxide is dissolved in water, both sodium ions and hydroxide ions are produced, as shown in the chemical equation below:

$$NaOH_{(s)} \xrightarrow{H_2O} Na^+_{(aq)} + OH^-_{(aq)}$$

Over time, scientists have extended their definition of acids and bases beyond Arrhenius' definition to be more inclusive. You will learn more about the contributions of scientists like Johannes Bronsted of Denmark, Thomas Lowry of England, and Gilbert Lewis of the United States in further chemistry courses.

Neutralizing Acids and Bases

When acids and bases react together in solution, the hydrogen ions and hydroxide ions react in a one-to-one ratio to produce water. The remaining ions can join to form a salt. The process of an acid and base reacting to form water and a salt is called **neutralization**. Because the hydrogen ions and hydroxide ions have formed water, the solution is said to be neutral. The process of neutralization is shown in the chemical equations below. The chemical formula for water is actually H_2O. In the equations below the formula is written as HOH, so that you can see where the hydrogen and hydroxide ions end up.

$H^+_{(aq)}$	+	$OH^-_{(aq)}$	→	$HOH_{(aq)}$		
hydrogen ion		hydroxide ion		water		
$HCl_{(aq)}$	+	$NaOH_{(aq)}$	→	$HOH_{(aq)}$	+	$NaCl_{(aq)}$
acid		base		water		salt

If a suitable indicator is added to the reaction system, it will change colors when neutralization occurs. The point at which the indicator changes color is called the endpoint.

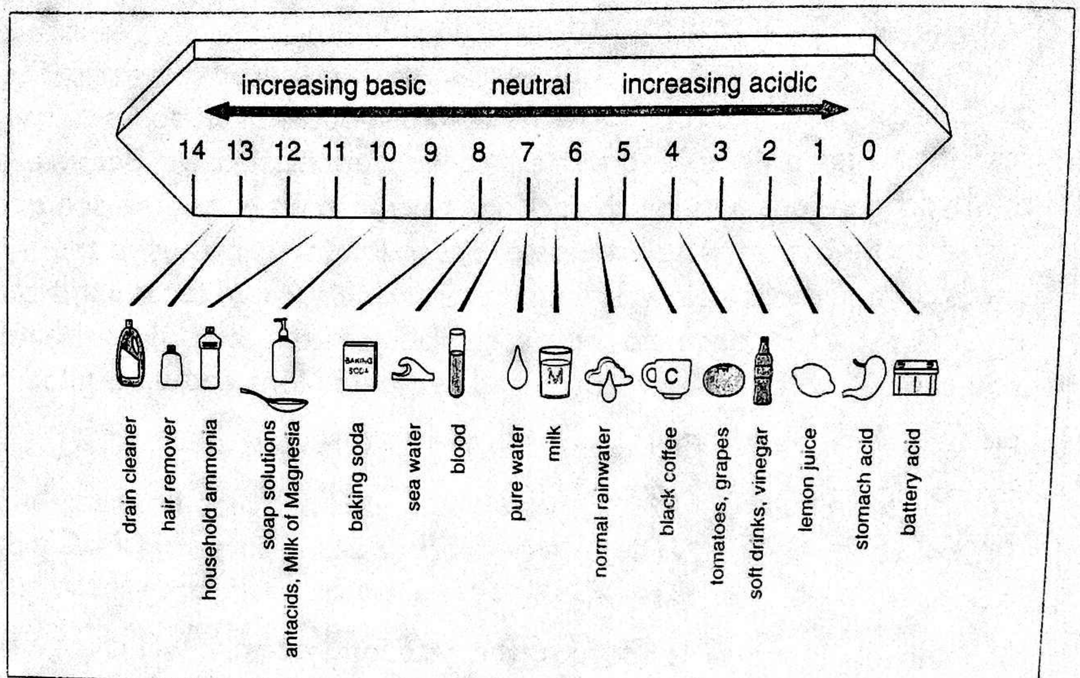
Consider the reaction of a strong acid (HCl) and a strong base (NaOH), as shown in the equation above. These substances are described as "strong" because they ionize completely in solution. For every HCl molecule, one hydrogen ion is released. For every NaOH, one hydroxide ion is released. These two ions then combine in a one-to-one ratio to form a neutral water molecule. Chemists take advantage of the neutralization process to help determine the concentration of solutions of acids or bases.

The pH Scale

In this activity you observed that one way of describing acids and bases is by examining their effects on indicators. Scientists also use the pH scale to express how acidic or basic a solution is. This number scale ranges from 0 to 14. Acid solutions have a pH less than 7. The more acidic a solution is, the lower the pH. Base solutions have a pH greater than 7. The more basic a solution is, the higher the pH. Neutral solutions have a pH of 7. The pH of a substance can be measured using methods like a pH meter or probe, pH paper, or universal indicator solution.

Chem Words

neutralization: the process of an acid and base reacting to form water and salt.



Acid and base indicators are compounds that are sensitive to pH. The color of the indicator changes as the pH of the solution changes. Most indicators are weak acids or weak bases that typically exhibit two different colors under varying pH conditions. The table below shows some common laboratory indicators and the colors they display under different pH conditions.

Common Laboratory Acid-Base Indicators

Indicator	**Color Change**	**pH Range**
methyl violet	yellow to blue	0.0 to 1.6
thymol blue	red to yellow	1.2 to 2.8
methyl orange	red to yellow	3.2 to 4.4
bromocresol green	orange to violet	3.8 to 6.4
methyl red	red to yellow	4.2 to 6.3
litmus paper	red to blue	5.5 to 8.0
bromothymol blue	yellow to blue	6.0 to 7.6
phenolphthalein	colorless to red	8.2 to 10
thymolphthalein	colorless to blue	9.4 to 10.6
cabbage juice	red to green	2 to 12 (universal)

The pH scale ranges from 0 to 14 and is used to express the concentration of the hydrogen (H+) or hydronium ion (H_3O^+) of a solution at 25°C. Mathematically, it is defined as the negative logarithm of the hydrogen ion concentration. The term **pH** stands for **p**ower of **H**ydrogen ion. It can be written as:

$$pH = -\log_{10}[H^+]$$

where the brackets [ ] stand for "concentration of" (hydrogen ions in solution). Because pH is a logarithmic scale, the concentration of the hydrogen ion $[H^+]$ actually increases or decreases tenfold for each unit on the scale. An acid with a pH of 2 has a $[H^+]$ that is 10 times greater than an acid with a pH of 3 and 100 times the concentration of an acid with pH 4. A base with a pH of 10 has a $[H^+]$ that is 10 times less than a base with a pH of 9.

Chem Words

pH: a quantity used to represent the acidity of a solution based on the concentration of hydrogen ions ($pH = -\log[H^+]$).

Checking Up

1. Use a chart to compare the properties of acids and bases. Be sure to include headings like taste, feel, pH, and reaction with metals.
2. What characteristic property did Arrhenius attribute to acids and bases?
3. Describe the process that occurs when an acid reacts with a base.
4. Why are litmus paper and phenolphthalein particularly useful indicators for distinguishing between acids and bases?
5. What does pH stand for?
6. How much more acidic is a solution of pH 3 than pH 5?

Reflecting on the Activity and the Challenge

In this activity you expanded your knowledge about acids and bases by becoming familiar with many of their characteristics. You learned about Arrhenius' definition of acids and bases. You also learned a bit about pH, another way of expressing the acid or base nature of substances. This information will all come in handy as you plan your presentation for the Cool Chemistry Show. Remember that the fifth-grade teacher has specifically asked that your class includes presentations and information about acids and bases.

Chemistry to Go

1. Identify which of the following characteristics relate to acids and which relate to bases:

   a) taste sour

   b) release hydroxide ions ($OH^-_{(aq)}$) when dissolved in water

   c) feel slippery

   d) release hydrogen ions ($H^+_{(aq)}$) when dissolved in water

   e) turn pink in the presence of phenolphthalein

   f) react with metals to produce hydrogen gas

   g) taste bitter

   h) turn red cabbage juice indicator green

2. Use Arrhenius' definition of an acid to help you write a chemical equation that shows the acidic nature of the following:

   a) sulfuric acid (H_2SO_4)

   b) carbonic acid (H_2CO_3)

3. Use Arrhenius' definition of a base to help you write a chemical equation that shows the basic nature of the following:

   a) potassium hydroxide (KOH)

   b) calcium hydroxide ($Ca(OH)_2$)

4. If you prepared the same concentration of two strong acids, sulfuric and hydrochloric, why would the pH of sulfuric be smaller than the hydrochloric acid?

5. Distilled water should have a neutral pH of 7, but water often has a pH less than 7. Suggest a reason for this lowering of the pH.

6. If you bubbled carbon dioxide through water, what would the new pH of the solution be?

7. Lemon juice, curdled milk, vinegar, all taste sour. What other properties would you expect them to have in common?